

Design and Testing of Boost Type DC/DC Converter for DC Motor Control Applications

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Abstract— This paper presents the design and testing of a boost type DC/DC converter circuit, which can be used for DC motor control applications. The Boost converter is designed using DC chopper and DC chopper cascade configurations. The experimental setup was made by connecting the boost converter circuit with four types of DC motor, i.e. self-excited DC motor shunt, series, compound and separately excited DC motor. The motor was then coupled with a powderbreak as the load. The testing results show accepted performance, where the DC motor speed can be increased due to the increments of the output voltage of the DC/DC converter. The performance test comparison between the DC chopper and DC chopper cascade has presented that both converters have almost the same capability to drive the DC motors. Without load, the DC/DC converter can drive the DC motors to rotate at about 440 rpm at 15V dc supply and 1400 rpm at 55V dc supply. Coupling the motor with load will decrease the motor speed at about 346 until 505 rpm, depending on the load torque value and the DC motor types. (*Abstract*)

Index Terms—DC/DC Converter, Boost Converter, Motor Control, DC Motor (*key words*)

I. INTRODUCTION

The EVs (Electric Vehicles) and HEVs (Hybrid Electric Vehicles) can use either DC (direct current) motors or AC (alternating current) motors as its main drive system. The use of DC motor requires simpler converter circuit, because they do not need an inverter circuit. The inverter is used to change the DC output voltage of the car's battery into AC voltages, which is required by the AC motors. Before, the DC voltages is inverted, the DC source should be commonly stepped up into a certain level in accordance with the required magnitudo level of the AC signal.

Boost type DC/DC converter is a circuit used to step up or to boost input voltages of the circuit, normally from battery, into upper level voltages, which required by the DC motors. The boost converters are widely used in electric vehicle (EV) and hybrid electric vehicle (HEV) applications, which use DC motors as its main drive system.

The DC motor speeds rely with the input voltage levels applied to the motor terminal. The higher the voltages, the higher the motor speeds. By using a battery as the power source, having a DC output voltage level, we then require a boost converter used to step up the battery's DC voltage level in order to be able to speed up the DC motor rotations.

Figure 1 shows an example of the DC chopper cascade circuit used to control the DC motor speed, which is coupled with a load. The output voltage level of the DC chopper circuit can be increased by increasing the duty cycle of the PWM (pulse width modulation) control signal generated by a pulse generator modul. The PWM control signal is applied to the Power MOSFET in the circuit to change the output voltage levels of the DC/DC converter circuit.

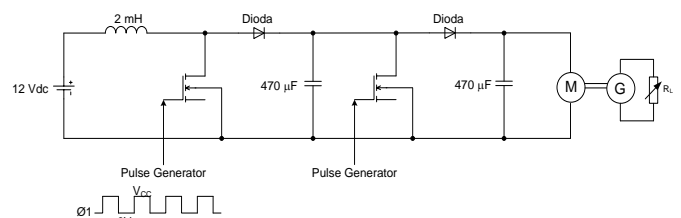


Figure 1. The DC/DC converter circuit using DC chopper cascade configuration for motor control applications.

II. PROBLEM DESCRIPTION AND OBJECTIVES

In EVs and HEVs application, the voltage level of the battery is commonly lower than the minimum and the maximum requirements of the DC motor to rotate at minimum and maximum speed. Therefore, we need Boost type DC/DC Converter to step up the voltage level of the battery. This paper will investigate the behavior of DC chopper and DC chopper Cascade circuits to attain their maximum voltage boosting capacity. In order to find out the best circuit characteristics we then need to model the circuits by using SPICE (Software Program with Integrated Circuit Emphasis). During the investigation, we will verify the converter characteristics obtained from simulation with the real performance test of the implemented DC/DC converter circuit.

III. RELATED WORKS

Based on the output voltage level, DC/DC converters can be divided into Step-Up (Boost) Converter, Set-Down (Buck) Converters and Buck-Boost Converters. A Buck converter is used to provide a voltage level lower than its input voltage range. A Boost Converter is used to provide a voltage level higher than its input voltage range. A Buck-Boost Converter is accordingly is able to provide an output voltage level lower or higher than its input voltage range [1].

This paper presents the design, simulation and test of a boost converter that can be used for example in EVs or HEVs applications. Based on the used circuit configuration, boost converters can be classified into charge-pump and chopper type converters. Charge pump converter have been widely used in many application [2,3,4,5,6,7]. Dikson Charge Pump, an example of a charge pump configuration, has been investigated by some research groups.

For the same frequency domain, the DC/DC chopper cascade, another type of boost converter, has presented higher output voltage level capability [10]. We are still investigating the results, and yet analysis the potential capability of this charge pump circuit configuration. The main advantage of the charge pump is the absent of inductor. Thus, it is also known as inductorless DC/DC converter. Due to this feature, all charge pump components can be integrated into a single integrated circuit [8]. The use of CMOS technologies has also supported the development of charge pump based converters, especially to support high-voltage applications [9].

This paper present the design, simulation and test of DC/DC chopper and DC/DC chopper cascade converter as the advanced dissemination from our previous work [10].

IV. CIRCUIT MODELING AND SIMULATION

We modeled the DC/DC chopper by using SPICE [11], simulate the circuit behavior and then realized the hardware prototyped for experiments. This section will only show the simulation results of the circuit behaviors and the analysis results. While the experimental results will be presented in the next section.

A. DC/DC Chopper

The circuit configuration of DC/DC chopper converter is illustrated in Figure 2. As shown in the figure, a load of the series resistive and inductive is connected to the output terminal of the circuit, and in parallel with Ce capacitor of 470uF.

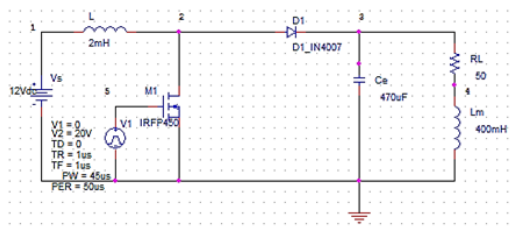


Figure 2. DC/DC chopper boost converter [10,11].

The simulation of the DC/DC chopper circuit is presented in Figure 3. We use PWM signal with the frequency of 20kHz. The load is a resistive (500ohm) and inductive (200mH) load in series and both are in parallel with a capacitive (270uF) load. We simulate the circuit by changing the dutycycle of the PWM signal, i.e. 50%, 60%, 70%, 80% and 90%.

As shown Figure 3, the output voltage level is increased as the dutycycle is increased, but the output voltage drops as the dutycycle is set to 90%. As the dutycycle is set to 50%, the output voltage steady at 50V level, 60V at dutycycle 60%. At dutycycle 80%, the circuit can boost the output voltage until 100V, but it drops to almost 80V as the dutycycle is 90%.

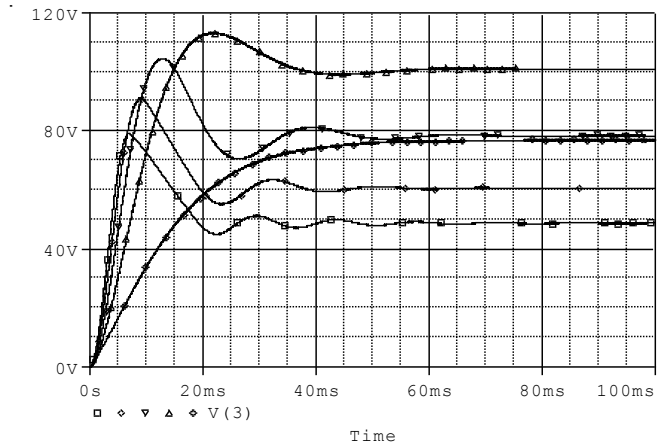


Figure 3. The simulation result of the DC/DC chopper boost converter with different duty cycle: 50%, 60%, 70%, 80% 90%, & signal period of 50us (freq. 20kHz).

Figure 4 presents the simulation result of the DC/DC chopper circuit by changing the value of the resistive load, i.e. 50, 100, 150 and 200Ohm. It seems that the output voltage level becomes higher as the the resistive is set larger. The output voltage becomes 100V as the resistive load is 500Ohm, and it becomes about 125V as the resistive load is 2000Ohm.

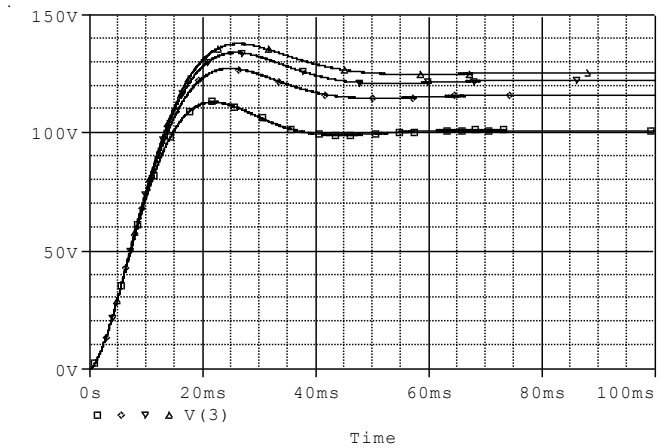


Figure 4. The simulation result of the DC/DC chopper boost converter with different resistif load (Rload): 50, 100, 150, 200Ohm and fixed dutycycle=80%, & signal period of 50us (freq. 20kHz).

B. DC/DC Chopper cascade

The circuit configuration of DC/DC chopper cascade converter is illustrated in Figure 2. Like the previous chopper simulation circuit, the output terminal of the circuit is connected with resistive-inductive load in series and in parallel with Ce capacitor of 470uF. In the chopper cascade circuit, the NMOS, diode and capacitor Ce is duplicated and connected in series to the output terminal of the single chopping circuit. Hence, in the chopper cascade configuration, we need two Power NMOS devices, where each of them required the same switching control signal, i.e. a the same PWM for both power NMOS.

The simulation of the DC/DC chopper cascade circuit is presented in Figure 6. Like the previous simulation, we use PWM signal with the frequency of 20kHz. The load is also a resistive (500ohm) and inductive (200mH) load in series and both are in parallel with a capacitive (270uF) load. We

simulate the circuit by changing the dutycycle of the PWM signal, i.e. 50%, 60%, 70%, 80% and 90%. As shown in the figure, the output voltage level tends to be higher as the duty cycle is increased from 50% to 60%. However, as the dutycycle is set to 70%, 80% and 90%, the output voltage drops to lower level.

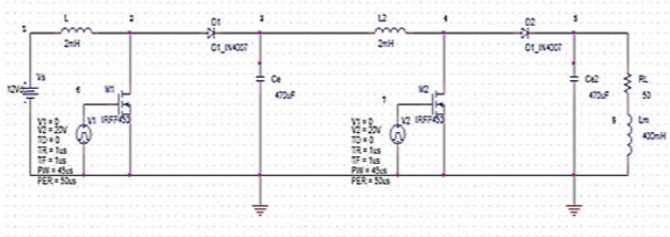


Figure 5. DC/DC chopper cascade boost converter [10].

When the dutycycle is set to 50% the duty cycle is steady at about 95V level, and 115V at dutycycle 60%. As the duty cycle is set to 70%, the output voltage drops to 110V, and becomes lower at about 68V level, as the dutycycle is set to 90%.

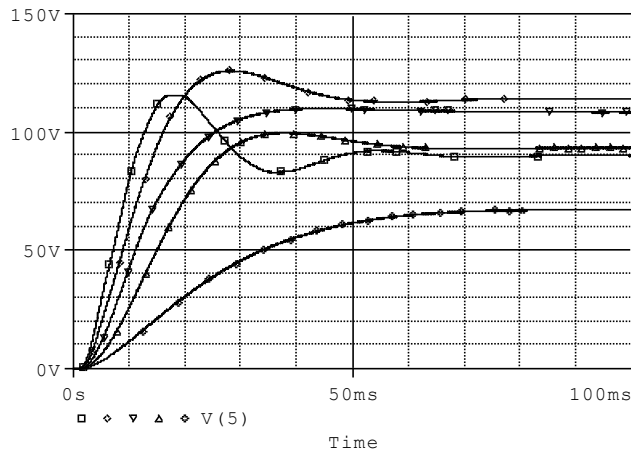


Figure 6. The simulation result of the DC/DC chopper cascade boost converter with different duty cycle: 50%, 60%, 70%, 80% 90%, & signal period of 50us (freq. 20kHz).

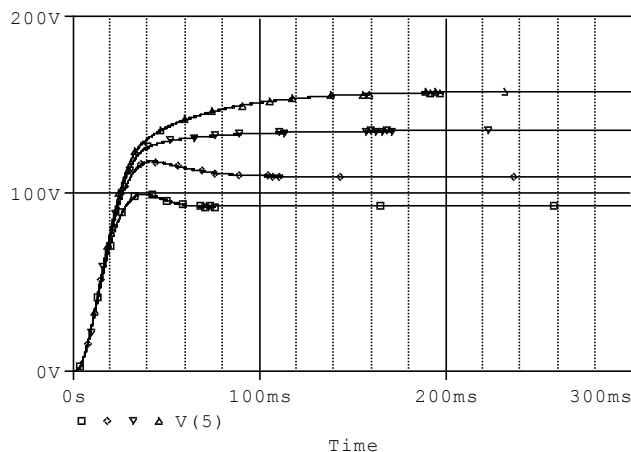


Figure 7. The simulation result of the DC/DC chopper cascade boost converter with different resistif load (Rload): 50, 100, 150, 2000ohm and fixed dutycycle=80%, & signal period of 50us (freq. 20kHz).

Figure 7 presents the simulation result of the DC/DC chopper cascade circuit by changing the value of the resistive

load, i.e. 50, 100, 150 and 2000ohm. It seems that the output voltage level becomes higher as the the resistive is set larger. When the resistive load is set 500ohm, the ouput voltage level of the chopper cascade is about 90V. At 2000ohm, the output voltage is about 150V. This resistive-load-voltage characteristic is similar to the results presented by the single chopping configuration.

Figure 8 presents the simualtion result of the DC/DC chopper cascade circuit, where the frekuensi or the period of the PWM signal is increased, i.e. at 50us, 60us, 70us, 80us and 90us. We can see fromt the figure that the output voltage level does not change significantly.

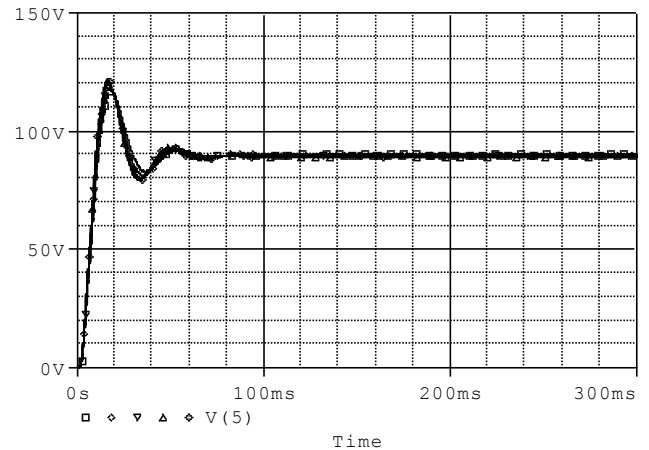


Figure 8. The simulation result of the DC/DC chopper cascade boost converter with different resistif PWM signal period: 50us, 60us, 70us, 80us, 90us, and with fixed dutycycle=50%.

I. HARDWARE IMPLEMENTATION AND TESTING

In this section, the real hardware prototyping of the DC/DC chopper-type boost converter is presented. We use three types of DC motors as the system loads. The used motor types are self-excited DC motor with shunt, series and compound circuit configurations, and a separately excited DC motor.

A. Experimental Setup

There are two experiments that we setup to test the real performance of the designed boost converter. The first experiment is the performance test of the DC/DC converter to control DC motor speed without load. To test the boost converter performance, we use self-excited and separately excited DC motors. For the self-excited DC motors, we use the Shunt, Series and Compound DC motors. The second experiment is the performance test of the DC/DC converter to control the DC motor with variable load.

The input voltages of the DC/DC converter are 12V and 24V. The PWM control signal for the Power MOSFET is generated by an 8-bit microcontroller. The PWM control signal is measured by using oscilloscope. Figure 9 presents the partial view of the experimental conditions.

B. Testing and Measurement Results

Figure 10 presents the speed measurements in rpm (rotation per minute) of the DC shunt motor with the variable applied voltages of the boost converter, where in this case, no load is coupled to the motor shaft. We can see from the figure, that the

motor speed can be increased by increasing the voltage inputs applied to the DC shunt motor terminal. At 15V for example, the speed of the motor is about 440 rpm, and it can achieve 1410 rpm at 55V DC supplied by the DC/DC converters.

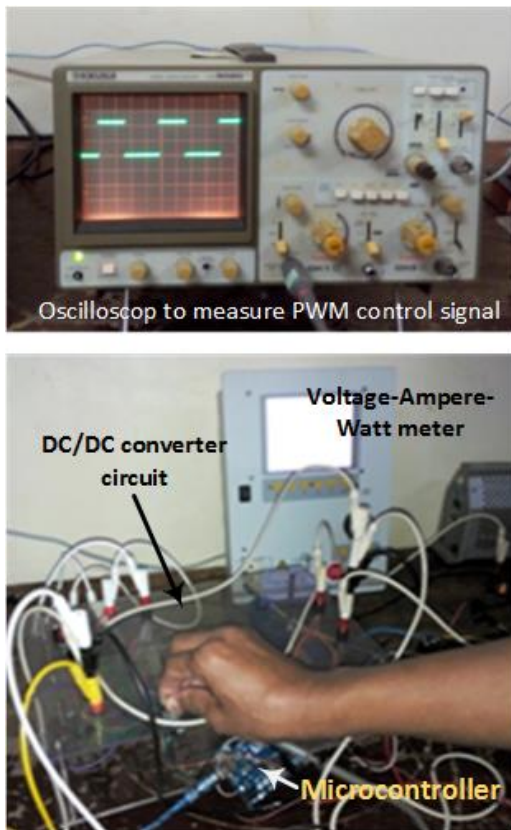


Figure 9. The partial experimental condition.

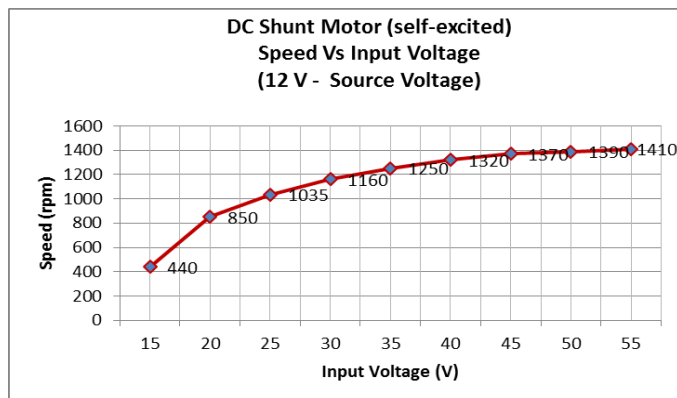


Figure 10. The speed measurements of the DC shunt motor with the variable applied voltages of the boost converter (no load).

We have also compared the simulation results of the chopper and chopper cascade circuit model in SPICE with the testing results obtained directly from the hardware prototyping. The comparison result is presented in Figure 11. The simulation is done with 12V DC applied to the input terminal of the circuits. As illustrated in the figure, the testing results from hardware prototype are different with the simulation results from the SPICE circuit model. The difference is probably caused by several aspects, such as the ideal

parameters used in simulation, and the different NMOS models utilized in the SPICE and the real NMOS devices used in the hardware prototype.

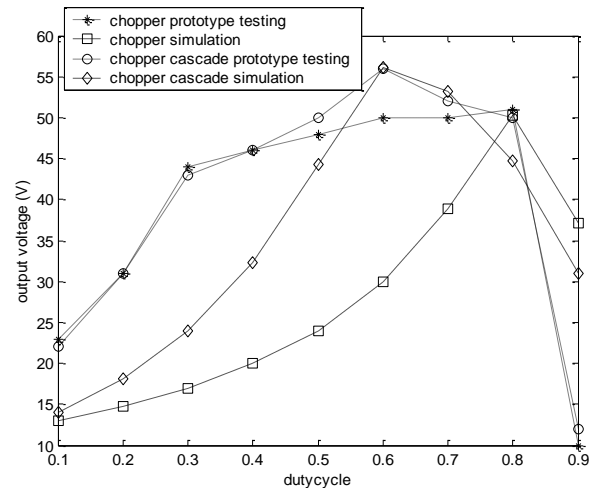


Figure 11. The comparison between circuit simulation and the testing results from the real hardware prototyping with 12V DC input voltage.

Table I shows the measurements of the DC motor control application by using the DC chopper cascade DC/DC converter. Four types of DC motors are experimented to test the impact of the load torque (in this case we use powderbreak load) to the motor speeds. From the table, it seems that the motor speeds in general are decreased due to the increments of the load torque. The DC voltage supplied to the DC motors are kept constant at 50V. In our experiment, we cannot drive the motors coupled with Powderbreak load, as the input voltage supplied to the DC/DC chopper cascade converter is 12V. We supplied it with 24V DC input so that the DC motors can be driven to certain speeds as presented in Table I.

TABLE I. Testing results with variable load, 50V DC supplied by DC/DC converter chopper cascade with 24V DC input voltage.

Load Torque (Nm)	DC Motor (Self-excited)			DC Motor (Separately excited)
	DC Shunt Speed (Rpm)	DC Series Speed (Rpm)	DC Compound Speed (Rpm)	
0.00	780	581	640	622
0.05	500	346	520	545
0.10	300	230	420	505

II. CONCLUSIONS

This has presented the comparative study between DC/DC converter chopper type and chopper cascade configuration. The simulation and testing results shows that the chopper cascade has better capability to step up the input voltage into higher voltage level values.

The chopper cascade DC/DC converter has been realized in a hardware prototype, and tested its performance with four types of DC motors with and without load. At no load condition, the chopper cascade can still drive the DC motors.

But, as the DC motors are coupled with a powderbreak load, the chopper cascade converter cannot drive the motors at 12V DC supply. By using 24V DC supply, the chopper cascade converter can drive the DC motor at lower rpm compared to the test without load. When coupled with 0.10 Nm load torque, the relatively highest rotational speed is obtained when 50V DC chopper cascade converter's output voltage is used to drive the separately excited DC motor, i.e. about 505 rpm.

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